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PRESSURE WAVE MEASUREMENTS RESULTING FROM THERMAL COOK-OFF OF THE HMX BASED HIGH EXPLOSIVE LX-04

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Abstract. Experiments that investigate thermal and nearby explosion scenarios are needed to provide essential data to models for accurate predictions. A porous LX-04 (85/15 wt% HMX/Viton) sample was heated in a heavily confined donor charge until it thermally exploded. The reaction accelerated a steel cover plate across a 10 cm gap into a preheated gauged acceptor cylinder (near its theoretical maximum density) of LX-04. The carbon resistor gauges in the acceptor measured the resulting multi-dimensional ramp wave as it propagated through the pre-heated LX-04. Detonation of the LX-04 acceptor does not occur. Results are compared to similar experiments with acceptors at room temperature.

INTRODUCTION

Because questions exist on the level of violence as a function of confinement and thermal heating rates in thermal explosion events, a better understanding is needed for safe handling, transportation, and storage of explosive devices. Experimental measurements of the violence of thermal explosion events of known sizes, confinements, and thermal histories are essential for developing and calibrating reactive flow computer models for calculating events that are impossible to measure experimentally. In addition, the measured accelerations of metal cases from thermal explosions are also needed to assess whether the resulting flying fragments can shock initiate violent reactions or detonations in neighboring explosive items.

The experiments performed here are referred to as Thermal EXplosion Tests (TEXT). Compared to experiments with slow hating rates of ~1°C/hour [1], the relatively quick heating rate (~5.7°C/min until 170°C, then 1°C/min until explosion) used here allows the combined results to bound the problem. Successful modeling of these two bounds will aid in the understanding of the mechanisms involved. In this paper, pressure gauge measurements are used to quantitatively determine the level of violence in a cook-off experiment and are used to measure low-pressure ramp waves with pulse widths of several microseconds. Carbon resistor gauges [2,3,7,8] have been successfully used in two-dimensional shock wave experiments where time resolution and accuracy were sacrificed for gauge survivability [2-6].

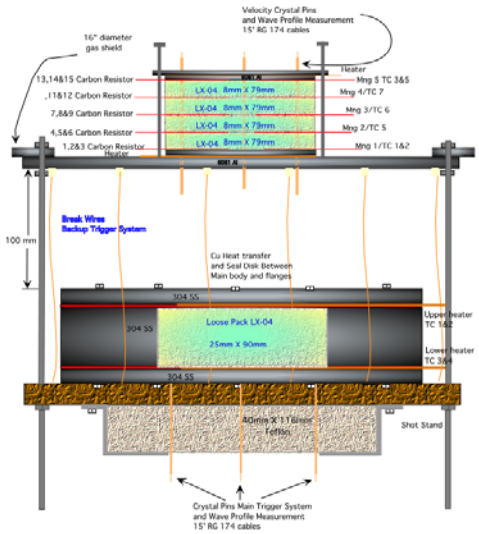

FIGURE 1. Diagram of the TEXT X experiment assembly.

EXPERIMENTAL PROCEDURE

Three thermal explosion experiments were performed using LX-04 donor charges confined in 304 stainless steel cased donor assemblies. Experiment TEXT VIII used a 1.86 g/cc (98.5% TMD) LX-04 donor charge with a 1.86 g/cc (98.5% TMD) LX-04 acceptor assembly in intimate contact with the donor. A follow up experiment, TEXT IX, was performed using a porous LX-04 donor charge at 1.05 g/cc (55.6% TMD) and a Teflon acceptor in intimate contact with the donor. TEXT X is the third experiment with LX-04 and utilized a porous LX-04 donor (55.6% TMD) and a heated 1.86 g/cc (98.5% TMD) LX-04 acceptor assembly at a 10 cm standoff.

Experiments TEXT VIII and TEXT IX were detailed in a prior publication [6] and will not be fully described here, but will be referred to in the following sections for comparison and discussion. The experiment TEXT X is shown in Figure 1 with the 79 mm diameter LX-04 acceptor placed at a 100 mm standoff from the top steel plate of the donor. Manganin and carbon resistor gauges were placed at the interfaces of the acceptor discs at 0, 8, 16, 24, and 32 mm from the front face of the acceptor HE. The acceptor was sitting on a 9.3 mm thick 304 stainless steel plate placed 100 mm from donor's steel top plate. Extensive details about the donor assembly, donor heating system, carbon resistor pressure gauges, manganin pressure gauges, thermocouples, PZT pins, pin placement under donor, and acceptor pin placement (15 mm and 25 mm standoff) are the same as previous experiments [4,6].

Heating of the donor occurred at a rate of 5.7°C a minute until the thermocouples at the heater package recorded 170°C and soaked for about 30 minutes. Then the heating rate in the heater package was set at 1°C/min until the explosive thermally reacted. Unique to the experiment described in detail here, TEXT X, is the heating of the acceptor unit. The acceptor was heated in the range of 90-100°C at the time of donor cook-off. Because of the large thermal mass at the base of the acceptor assembly, the heating rate was rather erratic and will be discussed further in the results section. The assembled experiments were placed inside a large steel expendable cylinder before firing to protect the firing chamber walls.

RESULTS/DISCUSSION

The donor assembly in TEXT X cooked off as expected at approximately 230°C. The acceptor was in the temperature range of 90-100°C when this occurred and the donor cover plate was thrown into the acceptor. The velocity of this plate was measured as approximately 350 m/s as indicated by an average of the standoff pins protruding at 15 mm and 25 mm from stainless steel acceptor base. The pin arrival times varied indicating that the plate was probably curved like a door knob during impact and that it was not a planar impact.

As mentioned earlier, non-uniform heating of the acceptor was seen due to a large amount of metal surrounding the assembly acting to

conduct heat away as can be seen in Fig. 2. An overshoot is seen in the top of the acceptor (less metal thermal mass surrounding) as the controller was manually adjusted to slow it down to follow the base heating more closely.

The carbon resistor pressure gauge records are displayed in Fig. 3 and showed a ramp wave with a peak of approximately 0.7 GPa that decayed to about 0.2 GPa in the 32 mm thick LX-04 sample. The ramp wave in the acceptors did not build into a detonation. Note that these pressures are based on a calibration of the gauges at 25°C. The gauges have not yet been calibrated at the elevated temperature, but ambient temperature heating shows that the initial resistance changes less than 2% when heated to 100°C [8], so the change in calibration is expected to be relatively small.

These results are consistent with the previous LX-04 cook-off experiments. TEXT VIII had a full density donor during cook-off and did not have significant violence to even blow off the donor charge cover plates. This was the reason for going to the porous donor in TEXT IX, which sent a ramp wave into the Teflon acceptor in contact with donor top plate with peak pressures of 0.8 GPa and a decaying ramp wave. The porosity plays an essential part in allowing the LX-04 to accumulate appreciable violence during thermal explosion.

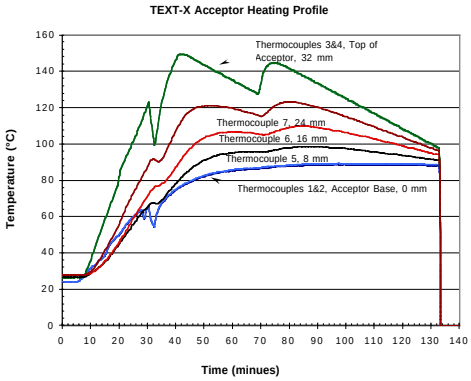

FIGURE 2. Heating profile of the acceptor assembly.

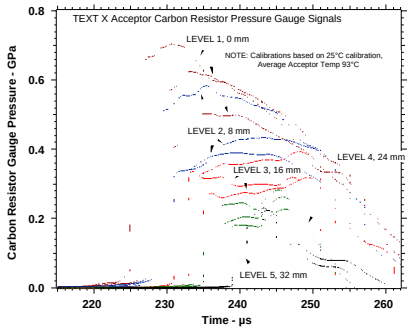

FIGURE 3. Pressure profiles of the carbon resistor gauges in the acceptor assembly.

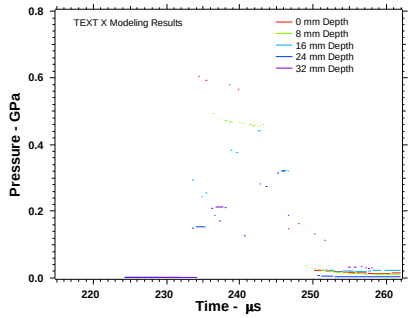

FIGURE 4. Modeling calculations of the pressure profiles at carbon resistor gauges locations in the acceptor assembly.

The DYNABURN option of the Ignition and Growth model was used as in Forbes et al. [6] to calculate experiments TEXT IX and X. The only changes were to lower the initial LX-04 density to 1.05 g/cm^3, the shear modulus to 0.9 GPa, the yield strength to 0.03 GPa, and the initial energy to 0.058 Mbar-cm^3/cm^3-g. The growth of reaction coefficient G_1 was adjusted to yield a low density LX-04 deflagration velocity that accelerated the steel plate in TEXT X to a final velocity of 350 m/s. This deflagration velocity also yielded good agreement with the pressures measured in the teflon acceptor in TEXT IX. Figure 4 shows the calculated pressure histories at the various gauge depths in heated LX-04 used in TEXT X, which can be compared to the experimental measurements shown in Fig. 3. The calculated peak pressures agree well with the gauge records, but the gauges show longer rise times and later arrival times. To improve the model

results, the simple low-pressure elastic-plastic description of LX-04 needs to be more complex. The full density LX-04 reactive flow model suggests that the heated LX-04 acceptor did not react at all in TEXT X.

SUMMARY AND FUTURE WORK

A porous LX-04 donor assembly was cooked off and the assembly plate was accelerated into a nearby heated (100°C) acceptor at a 10 cm standoff. The carbon resistor pressure gauge results (without temperature corrections) show ramp waves with peak pressures of 0.7 GPa and rise times of ~2μs. The ramp pressure wave decays very rapidly (i.e. does not build to detonation) as it moves through the acceptor charge and the rise times become more dispersed. The DYNA2D modeling of this experiment yielded results that are in good agreement with the experiment.

Future work includes TEXT XI as seen in Fig. 5 and TEXT XII experiments that are built and awaiting firing. These experiments use less confinement in the donor assembly with different thickness cover plates. The donor densities are near 1.0 g/cc.

FIGURE 5. Schematic diagram of the upcoming TEXT XI experiment with less confinement.

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